EVALUATING SUMMER WATER DEFICIENCIES

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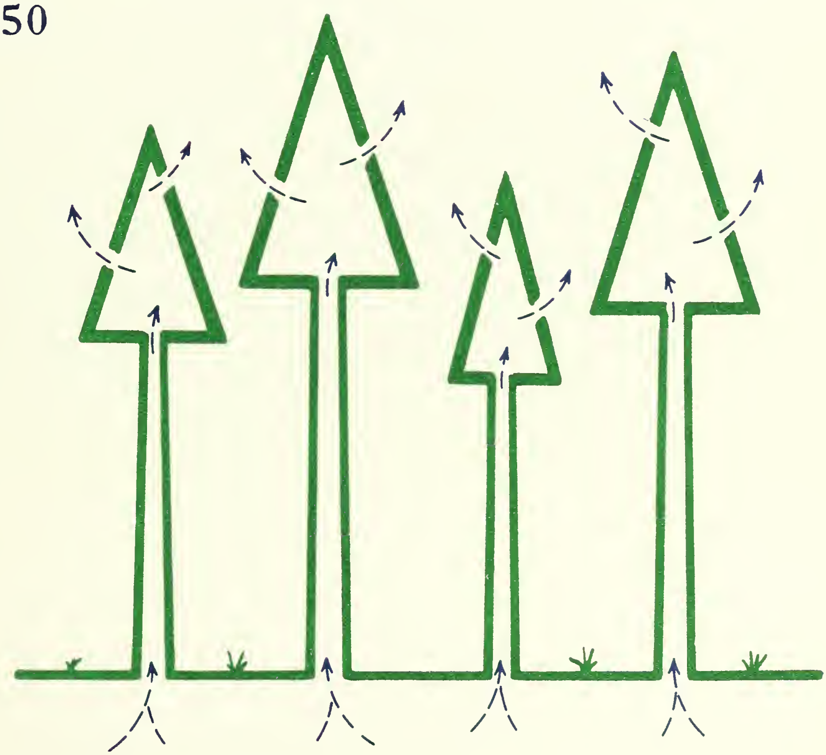

SOUTHERN FOREST EXPERIMENT STATION
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CONTENTS

THE MID-SOUTH OFTEN
FEELS THE EFFECTS OF DROUGHT

High
mortality

Slow
growth

Need for
replanting

EVALUATING SUMMER WATER DEFICIENCIES

Robert Zahner
Southern Forest Experiment Station

Of all the raw materials used by a tree in its growth and maintenance, that required in the largest amount is water. Drought, therefore, can be as serious to the forester as to the farmer.

It is important that the practicing forester understand what drought is and how to evaluate its intensity. He already has indirect measures of dry years, such as the number of days without rain or the number of inches less than normal rainfall. But a more basic measure is needed, a comparison between the water required and water available and actually supplied to forest trees.

This paper describes a method for measuring water deficiencies. Emphasis is placed on the upland pine-hardwood forests of the mid-South, but with a little modification the method can be adapted to many forest areas in the country.

Basically, the story is simple. Water for forest requirements comes from moisture stored in the soil. When this moisture is not replenished by rainfall, deficiencies occur. Correct analysis of soil-moisture storage and depletion is necessary to evaluate the deficiency.

Readers who are interested in some of the applications of calculated water deficiencies, but who do not wish to read through the details of theory and procedure, may turn directly to page 9.

BACKGROUND AND DEFINITIONS

Before water deficiency can be explained, other more basic definitions must be understood.

Evapo-transpiration.--Large quantities of water are removed from the soil by forest stands. The bulk of this water, however, is not used by the trees in the manufacture of food or in the formation of wood. It is transpired through the leaves into the atmosphere. This water loss, combined with evaporation directly from the ground surface, is evapo-transpiration. 1/

When evapo-transpiration is occurring at its maximum rate, it is supplying all the water that can be absorbed by the atmosphere under existing weather conditions. Early workers called this maximum rate "the evaporating power of the air" (7, 8, 11, 12, 15, 28). 2/ A better term for maximum water loss is potential evapo-transpiration, which has been defined as the amount of water that will be lost from a land surface completely covered with vegetation if there is ample water in the soil at all times for the use of the vegetation (14, 18, 19, 20). The energy for potential evapo-transpiration is present in the atmosphere whether or not vegetation and soil moisture are actually adequate for maximum evapo-transpiration. The potential, therefore, is the atmospheric demand for water.

Water need and supply.--Rainfall alone is not a very meaningful indicator of a wet or dry period. The water need of a forested area must be considered along with the water supply. The need is the amount of water that would be evapo-transpired if the energy of potential evapo-transpiration were completely utilized. The supply is the amount actually moving out of the soil into the air. The water thus moving may come from current rainfall, or it may have been stored in the soil from previous months.

In the mid-South the distribution of rainfall does not coincide with water needs. Because the need during the winter months is low,

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1/ Suggested for more detailed reading is H. W. Lull's compilation of related literature, Evapo-transpiration: Excerpts from Selected References. U. S. Forest Service South. Forest Expt. Sta. Occas. Paper 131, 117 pp. 1953.

2/ Underscored numbers in parentheses refer to Literature Cited, p. 16.

long periods without rain show no deficiencies and are of little consequence. It is with the summer period that the forester is concerned. At this time, actual evapo-transpiration can equal the high potential only when the soil is very moist. As the moisture in the soil is reduced, the actual amount of water evapo-transpired falls far below that which could potentially be passed into the atmosphere if ample moisture were available.

Water deficiency.--During any period when the forest soil cannot supply the full amount of water which the energy of potential evapo-transpiration could move into the atmosphere, there is a deficiency. The magnitude of the deficiency may be so small that it has no serious effect on forest growth and behavior. On the other hand, it can become quite large, with correspondingly disastrous effects. To evaluate the deficiency, both the potential evapo-transpiration (the water need) and the actual evapo-transpiration (the water supply) must be known. The numerical difference between the two can be termed the water deficiency.

Source of water.--In the upland pine-hardwood forests of the mid-South, the total water available to tree roots usually is only that held in storage by the soil particles themselves. Additional sources, such as lateral underground seepage or shallow water tables, are generally absent. The amount of stored water varies with soil texture and structure, with thickness of different soil horizons, and with other soil characteristics.

When rain has wet the soil for the entire depth of the root zone, and after excess water has drained away, the quantity of available water under a forest stand may vary on different soils from the equivalent of only about 5 inches of rainfall to as much as 15 inches.

Evapo-transpiration occurs at its maximum rate when the soil is at maximum storage capacity. At this level, water is held only loosely by the soil, and is easily removed. As the soil is depleted of moisture, the remaining water is held ever more tightly by individual soil particles, and the rate of evapo-transpiration decreases proportionately (1, 10, 17, 30, 31). As the soil approaches wilting point, during long periods without rain, actual evapo-transpiration becomes negligible. With each rainfall, the rate of evapo-transpiration picks up immediately.

ESTIMATING THE WATER NEED

The evaporating potential of the atmosphere is difficult to measure directly. Although solar radiation is the source of energy,

many factors--*e. g.*, air temperature, humidity, barometric pressure, and wind--modify the rate of evapo-transpiration. Transeau's (28) precipitation-evaporation ratio was an early attempt to find a climatic indicator of this energy. In measuring the evaporating potential, other investigators have constructed indices involving complex moisture-temperature relations and vapor-pressure deficits (7, 12).

Units of moisture-temperature indices and vapor-pressure deficits, however, are difficult to apply. Thornthwaite (20) has developed an empirical method for calculating potential evapo-transpiration from air-temperature data alone. His units of measure for potential evapo-transpiration are readily converted into inches of water, the standard measure of rainfall and other water-cycle variables. Thornthwaite's method has found many practical applications (4, 6, 13, 21, 22, 23, 24, 25, 27, 29).

From Thornthwaite's (20) method, it is apparent that the climate of the mid-South is sufficiently uniform to yield a nearly constant value for normal potential evapo-transpiration over the whole of the forested Gulf Coastal Plain area from Alabama to Texas. According to the method, the average monthly potential evapo-transpiration for five widely separated locations (Crockett, Texas; Hammond, Louisiana; Crossett, Arkansas; Tupelo, Mississippi; and Selma, Alabama) is 6.7 ± 0.4 inches for June, July, and August. Monthly variation within the summer season is small.

There is evidence that Thornthwaite's method may underestimate the summer water need in the mid-South. Forest stands in south Arkansas have been found to remove from the soil more than a quarter-inch of water per day through evapo-transpiration (16, 31, 32). Unpublished data of summer soil-moisture depletion by upland forests in Mississippi and in east Texas substantiate this figure. It would appear that the water need during June, July, and August is about 8 inches per month, and in the calculations outlined in this paper, this figure will be used in preference to the lower one (6.7 ± 0.4 inches) obtained by Thornthwaite's method.

Along with the hot summer months, the latter part of the warming period in the spring and the early part of the cooling period in the fall are important. Calculations by Thornthwaite's method from mid-South weather data show that the water need for May and September is about 5 inches for each month. That for October is half this amount, or about 2.5 inches. These figures are in close agreement with measured rates, and will be used in calculations of water deficiencies.

All values for water needs are estimates only, and are subject to modification as experience and further investigation warrant.

ESTIMATING ACTUAL EVAPO-TRANSPIRATION

In contrast to potential evapo-transpiration, actual evapo-transpiration is a highly variable factor. During the summer, when the water need is normally greater than rainfall, actual evapo-transpiration is equal to current rainfall plus changes in soil water storage. In June, for example, if rainfall is 3 inches and soil water storage is reduced 3 more inches, actual evapo-transpiration has supplied the atmosphere with 6 inches of water. Ignoring runoff, all rainfall of less than 8 inches for June, July, and August, of less than 5 inches for May and September, and of less than 2.5 inches for October, is used in evapo-transpiration during these months. Water entering the ground is only momentarily stored. Trees soon remove it in transpiration. Even intercepted rainfall, although never entering the soil, is evaporated directly from forest crowns and litter and is utilized in actual evapo-transpiration.

During long periods without rain, actual evapo-transpiration cannot keep pace with the water need. A forest can meet large water demands for a short time with the reserves stored in the soil, but soon stored water makes up only a part of the water need, and this part becomes ever smaller as the soil dries.

Although there is some variation with soil type, for practical consideration it can be assumed that the rate of moisture depletion by upland pine-hardwood forests is directly proportional to the moisture content of the surface six feet of soil--the effective root zone. For example, when a soil which is capable of holding 10 inches of water in the root zone is depleted of all but five inches, the rate of actual evapo-transpiration should be about half the maximum rate.

CALCULATING DEFICIENCIES

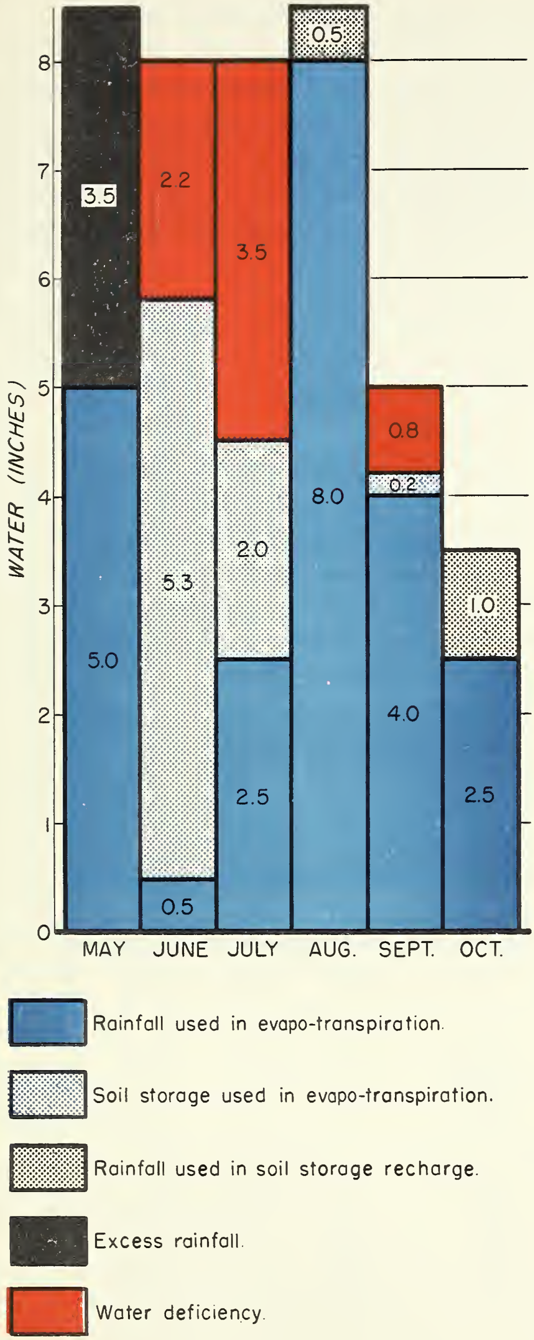
A detailed account of what is happening to the balance between supply and demand for water in any particular location can be kept as a bookkeeping procedure. As Thornthwaite and Mather (27, p. 350) state, "The moisture in the soil may be regarded as a bank account. Precipitation adds to the account; evapotranspiration withdraws from it." With irrigation, the farmer can keep his books balanced. The forester, although without irrigation, would like to keep an accurate account of the deficits.

Sample computation.--Summer water deficiencies can be systematically computed by employing the basic concepts discussed above. The following procedure has been adapted from Thornthwaite et al. (26, 27), for special use by foresters in the mid-South. The raw data necessary are rainfall records and the approximate soil moisture storage capacity of the site under consideration.

To illustrate the method, a sample computation is presented on p. 7, using hypothetical rainfall and soil storage data. In the step-by-step explanation, the reader may find it helpful to follow the procedure by means of the bar diagram. Water needs for the mid-South are given each month. Actual evapo-transpiration is assumed equal to these water needs during those months in which rainfall is equal to or greater than the need--as in May, August, and October, in this example. When rainfall is less than the need, as in June, July, and September, then actual evapo-transpiration is equal to the sum of rainfall plus the change in soil moisture storage. Usually soil storage cannot completely make up the difference, and the part not made up is the deficiency.

The actual amount of water supplied by the soil during a particular month depends on the storage capacity of the soil and on how much depletion has occurred during previous months. These values are taken from table 1, which has been constructed to simplify computations. This table is based on the premise that the amount of water supplied from soil storage becomes proportionally less as the soil dries; it shows amounts of water actually supplied by soil storage for any amount of water need in excess of rainfall. For comparisons between specific sites of known storage, the table gives water supplied by soils of four different storage capacities--6, 8, 10, and 12 inches. In this example, as for most practical purposes, an "average" storage capacity of 10 inches of water is assumed.

The application of table 1 requires some explanation. In the example, 7.5 inches of water are required during June for maximum evapo-transpiration. Reading down the 10-inch maximum storage column in table 1, it is seen that the soil can supply 5.3 inches. In July, 5.5 inches are required. Now computations must account for the accumulated two-month difference between rainfall and the water need. This is 13.0 inches, made up of 7.5 for June and 5.5 for July. Table 1 shows that the soil can supply 7.3 inches toward a 13.0 need. But 5.3 inches of this has previously been supplied during June, which leaves only 2.0 inches to be used in July. This accumulated effect may continue, with the soil becoming ever drier, supplying less and less water for actual evapo-transpiration, as long as rainfall is below the water need.



WATER NEEDS, SUPPLIES, AND DEFICIENCIES FOR THE SAMPLE COMPUTATIONS AT THE RIGHT.

CALCULATION OF WATER DEFICIENCY ON A HYPOTHETICAL FORESTED SITE WITH A MAXIMUM SOIL STORAGE OF TEN INCHES.

	INCHES
MAY	
RAINFALL	8.5
NEEDED	5.0
DIFFERENCE (Excess water)	3.5
REMAINING IN SOIL	10.0
JUNE	
RAINFALL	0.5
NEEDED	8.0
DIFFERENCE	−7.5
SUPPLIED FROM SOIL STORAGE	5.3
DEFICIENCY	**2.2**
REMAINING IN SOIL	4.7
JULY	
RAINFALL	2.5
NEEDED	8.0
DIFFERENCE	−5.5
SUPPLIED FROM SOIL STORAGE	2.0
DEFICIENCY	**3.5**
REMAINING IN SOIL	2.7
AUGUST	
RAINFALL	8.5
NEEDED	8.0
DIFFERENCE (Soil storage recharge)	0.5
REMAINING IN SOIL	3.2
SEPTEMBER	
RAINFALL	4.0
NEEDED	5.0
DIFFERENCE	−1.0
SUPPLIED FROM SOIL STORAGE	0.2
DEFICIENCY	**0.8**
REMAINING IN SOIL	3.0
OCTOBER	
RAINFALL	3.5
NEEDED	2.5
DIFFERENCE (Soil storage recharge)	1.0
REMAINING IN SOIL	4.0
TOTAL SUMMER DEFICIENCY	**6.5**

Table 1.--Relationship between water required and the water actually supplied by storage. Water required is the accumulated difference between rainfall and need

Accumulated difference between rainfall and need (inches)	Total maximum storage: 6 inches	8 inches	10 inches	12 inches
	Inches of water supplied by storage			
0.2	0.20	0.20	0.20	0.20
.4	.39	.40	.40	.40
.6	.58	.59	.59	.59
.8	.76	.78	.78	.78
1.0	.94	.96	.96	.96
1.2	1.11	1.14	1.14	1.14
1.4	1.27	1.31	1.32	1.32
1.6	1.43	1.48	1.49	1.50
1.8	1.58	1.64	1.66	1.68
2.0	1.73	1.80	1.83	1.85
2.2	1.87	1.96	1.99	2.02
2.4	2.01	2.11	2.15	2.19
2.6	2.14	2.26	2.31	2.35
2.8	2.27	2.40	2.46	2.51
3.0	2.39	2.54	2.61	2.67
3.2	2.51	2.68	2.76	2.83
3.4	2.63	2.81	2.91	2.98
3.6	2.74	2.94	3.05	3.13
3.8	2.85	3.07	3.19	3.28
4.0	2.96	3.19	3.33	3.43
4.2	3.06	3.31	3.46	3.57
4.4	3.16	3.43	3.59	3.71
4.6	3.25	3.54	3.72	3.85
4.8	3.34	3.65	3.85	3.99
5.0	3.43	3.76	3.97	4.13
5.2	3.52	3.87	4.09	4.26
5.4	3.60	3.97	4.21	4.39
5.6	3.68	4.07	4.33	4.52
5.8	3.76	4.17	4.44	4.64
6.0	3.83	4.27	4.55	4.76
6.2	3.90	4.36	4.66	4.88
6.4	3.97	4.45	4.77	5.00
6.6	4.04	4.54	4.87	5.11
6.8	4.11	4.63	4.97	5.22
7.0	4.17	4.71	5.07	5.33
7.2	4.23	4.79	5.17	5.44
7.4	4.29	4.87	5.27	5.55
7.6	4.35	4.95	5.36	5.66
7.8	4.40	5.03	5.45	5.77
8.0	4.45	5.10	5.54	5.87
8.2	4.50	5.17	5.63	5.97
8.4	4.55	5.24	5.72	6.07
8.6	4.60	5.31	5.81	6.17
8.8	4.65	5.38	5.89	6.27
9.0	4.70	5.45	5.97	6.37
9.2	4.74	5.51	6.05	6.46
9.4	4.78	5.57	6.13	6.55
9.6	4.82	5.63	6.21	6.64
9.8	4.86	5.69	6.29	6.73
10.0	4.90	5.75	6.36	6.82
10.2	4.94	5.81	6.43	6.91
10.4	4.98	5.86	6.50	6.99
10.6	5.01	5.91	6.57	7.07
10.8	5.04	5.96	6.64	7.15
11.0	5.07	6.01	6.71	7.23
11.2	5.10	6.06	6.78	7.31
11.4	5.13	6.11	6.84	7.39
11.6	5.16	6.16	6.90	7.47
11.8	5.19	6.21	6.96	7.55
12.0	5.22	6.25	7.02	7.62
12.5	5.30	6.35	7.17	7.80
13.0	5.35	6.45	7.32	7.97
13.5	5.40	6.55	7.46	8.14
14.0	5.45	6.64	7.57	8.29
14.5	5.50	6.72	7.70	8.44
15.0	5.55	6.79	7.82	8.59
16.0	5.61	6.94	8.02	8.86
17.0	5.66	7.07	8.22	9.11
18.0	5.71	7.17	8.39	9.35
19.0	5.76	7.27	8.54	9.55
20.0	5.81	7.37	8.69	9.75
22.0	5.88	7.49	8.91	10.09
24.0	5.93	7.59	9.11	10.39
26.0	5.96	7.69	9.29	10.63
28.0	5.98	7.79	9.39	10.83

August shows no deficit, since rainfall is greater than the need. September again requires water from soil storage. The accumulated difference between need and rainfall is now 13.5 inches, made up of 13.0 inches from June and July, minus the 0.5-inch recharge in August, plus 1.0 inch in September. Table 1 shows that the soil can supply 7.5 inches of this total. However, 7.3 inches of this have previously been used during June and July, leaving only 0.2 inch for use in September.

The winter months have very low water needs. Rainfall in excess of the need goes into soil storage recharge until the full 10-inch capacity is reached. Further excess rainfall then is lost through runoff and internal drainage.

Effect of runoff.--In the discussion above, it has been assumed that no runoff occurs when precipitation is below the potential evapo-transpiration. In the example just given, it was assumed that all of the rainfall of 0.5 inch in June and 2.5 inches in July entered the ground or was intercepted by foliage and litter. The total 3.0 inches, therefore, was assumed available for actual evapo-transpiration during June and July.

Depending on the intensity of showers, some of the rainfall during the growing season is actually lost as runoff. This amount is usually small, however, and in most summer showers on dry forested uplands of the mid-South can be ignored for practical purposes. In any case, water lost through runoff is not available for actual evapo-transpiration. The assumption that there is no runoff during the growing season therefore results in a conservative estimate of the actual water deficiency.

APPLICATIONS

The evaluation of water deficiencies has real meaning when applied under specific conditions. Two variables affect deficiencies: soil and weather conditions. The latter changes with time and place; i.e., from year to year and from one geographic location to another. When time and geographic regions are held constant, it is possible to evaluate water deficiencies of various sites within a region. When a site within a region is held constant, comparisons of deficiencies are possible among years, or even among months. Thus, it is possible to evaluate water deficiencies for many combinations or circumstances within the mid-South area. Following are some examples of how calculated deficiencies can be applied to specific cases.

Comparison among sites.--As emphasized earlier, the amount of stored water available for forest consumption varies greatly from site to site. The greater the amount of stored water, the longer the forest can supply the atmospheric demand for water during the summer period, and the smaller the deficiency. Figure 1 illustrates this principle for two sites on the Crossett Experimental Forest in south Arkansas. Normal rainfall data were used in computing the deficiencies, so that the average effects of the two sites might be compared.

The site storing 12 inches of available water in the root zone suffers a deficiency of nearly 7 inches during a normal summer. In contrast, the deficiency of an adjoining site storing only 6 inches of water is 40 percent greater--10 inches of water. On the latter site, a deficiency normally begins in May, whereas on the site storing more water, soil storage supplies the May requirements.

During a normal summer, all stored water is not used on the site storing 12 inches of water, and wilting point is not reached. On the site storing only 6 inches of available water, however, wilting point is closely approached.

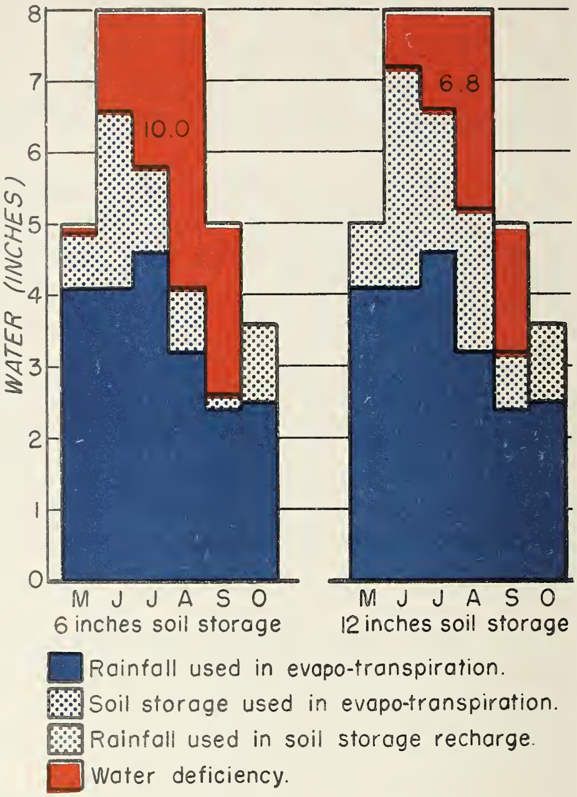


Figure 1.--Water needs and supplies for a normal summer at Crossett on two sites, one storing 6 inches and one storing 12 inches of available water in the root zone.

As has been mentioned, recharge of depleted soil water begins only after the demand by potential evapo-transpiration becomes less than is supplied by rainfall. For the Crossett area, recharge by rainfall does not normally begin before October. Assuming no runoff, all rain falling on the site storing 12 inches of water goes into the ground as storage until late December, when, in a normal year, recharge has completely replaced the 8.2 inches of depleted storage. This normal recharge occurs by early December on the site which stores only 6 inches of available water, as

only 5.4 inches of stored water is used. After recharge of the soil, rainfall in excess of potential evapo-transpiration is surplus water and is lost to both sites by runoff or by internal drainage.

Comparison among years. --Figure 1 shows that water deficiencies of about 7 inches can occur on a good site in the mid-South during a normal growing season. The forester is quite well satisfied with a "normal" year. The dry year, or drought year, is of concern.

Figure 2 shows the trends of precipitation and evapo-transpiration for the 6-year period of 1950 through 1955 for an average site on the Crossett Experimental Forest. The summers of 1950 and 1951 were considered wet, those of 1952, 1953, and 1954 were dry, and that of 1955 intermediate. Winter surpluses did not vary greatly from year to year, and averaged about 20 inches after soil storage recharge. The total excess of nearly 120 inches for the 6-year period certainly does not reveal the severity of the three drought years.

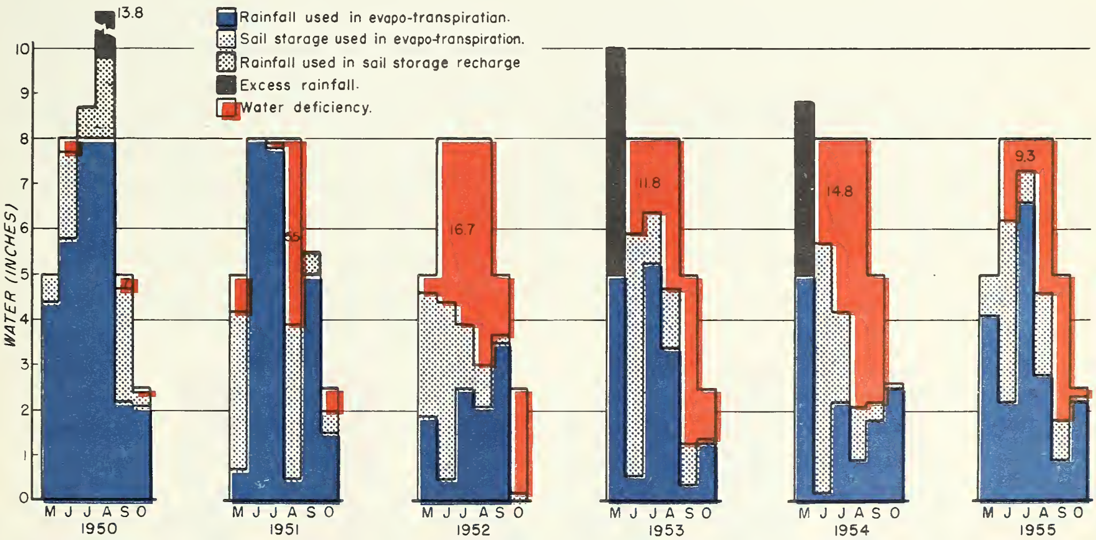


Figure 2. --Water needs and supplies for 1950-55 on the Crossett Experimental Forest. Computations were made for a site storing 10 inches of available water in the root zone.

Analyzed season by season, figure 2 reveals outstanding differences in water deficiencies for the Crossett area during the 6-year period. Deficiencies varied from 0.7 inch in 1950 to 16.7 inches in 1952. The result is a simple quantitative comparison of failures to meet the

water need from one growing season to another. Wilting point of the soil on this average site was closely approached in all years except 1950 and 1951. Sixty-five percent of available soil moisture had been removed from this site by the end of June in 1952, and about 55 percent had been lost by this date in 1953 and 1954. Ninety percent of available water was used during all three years by the end of August, with a dry September still ahead in all cases.

Dry periods within a season can be easily delineated and analyzed in detail. For example, of the 11.8-inch deficiency for Crossett in 1953, 4.8 inches (40 percent) occurred during September and October, while only 3.7 inches (30 percent) occurred during June and July. In 1952, dry conditions in May and June resulted in most of the stored water being used early in the season, a circumstance which greatly increased deficiencies from July through October. Other interesting examples are noted in June of 1953 and 1954. Even though monthly rainfall was only about one-half inch for each of these instances, actual monthly deficiencies were not high--in the neighborhood of only 2 inches each. In these periods stored soil water supplied most of the water required by potential evapo-transpiration, thus partly compensating for the lack of rain.

Comparison among locations.--The diagrams in figure 3 have been constructed from weather records of four locations throughout the mid-South. The normal trends of precipitation and evapo-transpiration are compared with those for the year 1954. An average soil storage of

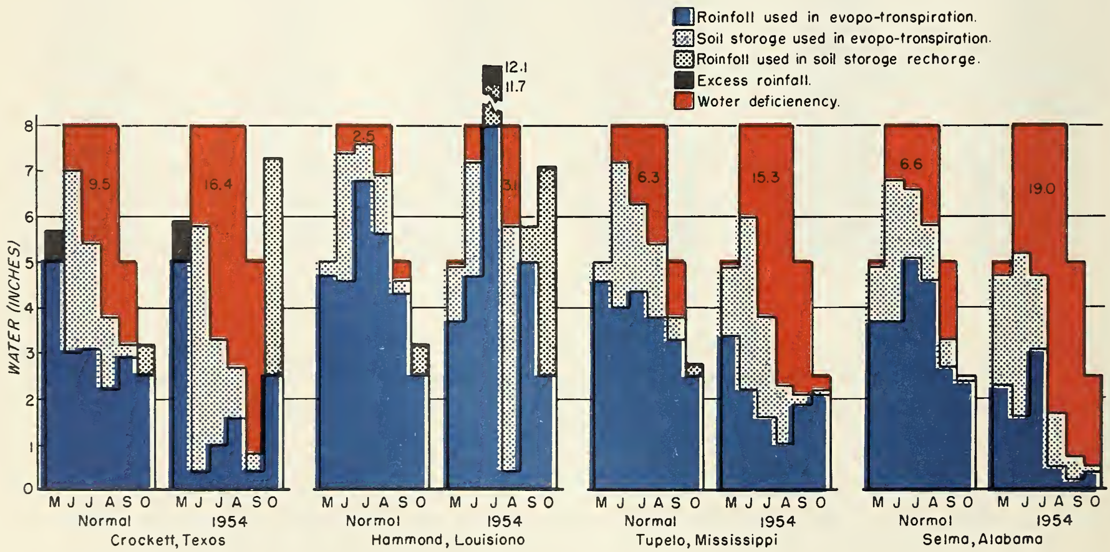


Figure 3.--Water needs and supplies for normal conditions and for the 1954 season, at four locations. Computations were made for a site storing 10 inches of available water in the root zone.

10 inches of water is assumed for all four locations. It is felt that this storage capacity is representative of most forested areas of upland Coastal Plain soils in the mid-South. For specific sites, summer deficiencies will be more or less severe than shown in the figure, depending on the actual amount of water stored in the root zone.

Crockett, Texas, normally has a rather large water deficiency, 9.5 inches, whereas Hammond, Louisiana, has relatively little, 2.5 inches. More than 80 percent of available soil water is used during the normal summer at Crockett, while only half this amount is used at Hammond. Forests at Tupelo, Mississippi, and Selma, Alabama, normally use about 75 percent of the stored water, and suffer a deficiency of between 6 and 7 inches of water.

During the summer of 1954, all stations except Hammond show severe water deficiencies, with Selma having the largest absolute deficiency. Although Hammond rainfall was less than one-half inch for August 1954, soil storage supplied most of the 8-inch water need, and the deficiency was only 3.1 inches for the month. At Selma, low rainfall early in the season used up most stored water, with the result that continuing dry weather accumulated a very large water deficiency in 1954.

In terms of departure from normal, the 1954 deficiency at Crockett was not so severe as that at Selma or Tupelo. Although Tupelo had a smaller absolute deficiency than did Crockett, it suffered a greater departure from normal. Hammond showed only minor departure from normal deficiency in 1954.

EFFECTS ON FOREST GROWTH

This paper does not offer experimental evidence of the effect of summer water deficiencies on tree growth. Instead, it is merely intended to present a useful and new concept of <u>how</u> summer water defiency can best be expressed. Certain generalizations about the relationship between tree growth and water deficiency appear in order, however.

The rate of forest tree growth is generally known to be related to the amount of available water in the soil (2, 3, 5, 9). There is increasing evidence that whenever soil moisture is deficient, the rate of forest growth is affected. New plantations are probably affected differently than stands of pulpwood or poles. These in turn may be affected differently than mature timber.

It is not yet known exactly at what level of water deficiency forest growth is affected. As long as actual evapo-transpiration keeps pace with the potential, the rate of growth should be at the maximum that the other factors (e. g., temperature, nutrient supply, photoperiod) will allow. When actual evapo-transpiration falls below the potential, then the water factor theoretically may affect growth. Even during a normal year in the Crossett, Crockett, Tupelo, or Selma areas, for example, maximum growth would not be attained during the June through September period--half of the growing season. During specific years, forest growth in these areas actually is proportionately higher or lower than normal, depending on the magnitude of water deficiency.

Comparisons of water deficiencies by sites, years, and geographic locations offer possible explanations for corresponding differences in forest behavior. Thus while the dry summer of 1954 was felt by forests in other parts of the mid-South, growth in the Hammond area may have suffered very little that year. Soil storage on the average site provided all but a very little of the water required during the one dry month. This situation extends to the normal year. Normal deficiencies are one-fourth to one-third less in the Hammond area than in the Crockett, Tupelo, or Selma areas. Moreover, calculations show that a soil at Hammond storing only 6 inches of available water normally suffers a smaller water deficiency than a soil at Crockett which stores 12 inches of water. Forest growth on poor soil in the Hammond area might therefore be as much as that on good soil in the Crockett area. Although it is not known whether water deficiency is largely reflected in reduced height growth, reduced diameter growth, or both, site index differences can probably be traced to differential water deficiencies.

Year-by-year comparisons of deficiencies on the average site in one location should yield corresponding forest growth comparisons. At Crossett, for instance, water relations were adequate for excellent growth throughout the summer of 1950. During the summers of 1952, 1953, and 1954, however, growth was adversely affected by the proportional amounts of the respective water deficiencies. In 1951, growth may not have been affected before August, for there was no deficiency in June and July.

Conservation of soil moisture through stand management--control of basal area, eradication of underbrush, removal of cull trees--minimizes the ill effects of water deficiency. Further investigations may discover practical ways of overcoming part of the deficiency felt nearly every summer by forests of the mid-South.

SUMMARY

Summer water deficiencies of upland forest land can be evaluated only when the water need is compared to the water supply. The atmospheric potential for evapo-transpiration is a measure of the need. Current rainfall plus stored soil water make up the supply. This paper describes a method for calculating water deficiencies by taking into account these factors of need and supply.

Normally, summer rainfall in many parts of the mid-South supplies only about half the water required by the high potential evapo-transpiration. Part of this difference is made up by water stored in the soil and removed by forest vegetation. That part not supplied is the deficiency. The more available water a soil inherently stores in the root zone, the less the deficiency during a dry summer period.

As long as the soil is moist, it supplies a large portion of the difference between rainfall and the water requirements of the atmosphere. As the soil dries, however, it supplies less and less water for evapo-transpiration, and the deficiency becomes greater and greater. During summer droughts, it is common for forest land to build up deficiencies of 15 to 20 inches of water in the mid-South.

Because the water need is considered relatively uniform over large areas in the mid-South, water deficiencies vary primarily with current rainfall and soil storage capacities. Using a minimum of data, it is possible to evaluate and compare deficiencies from site to site, from year to year, and from geographic location to location within the mid-South region.

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